Stress-Assisted Corrosion (SAC) in Boiler Tubes

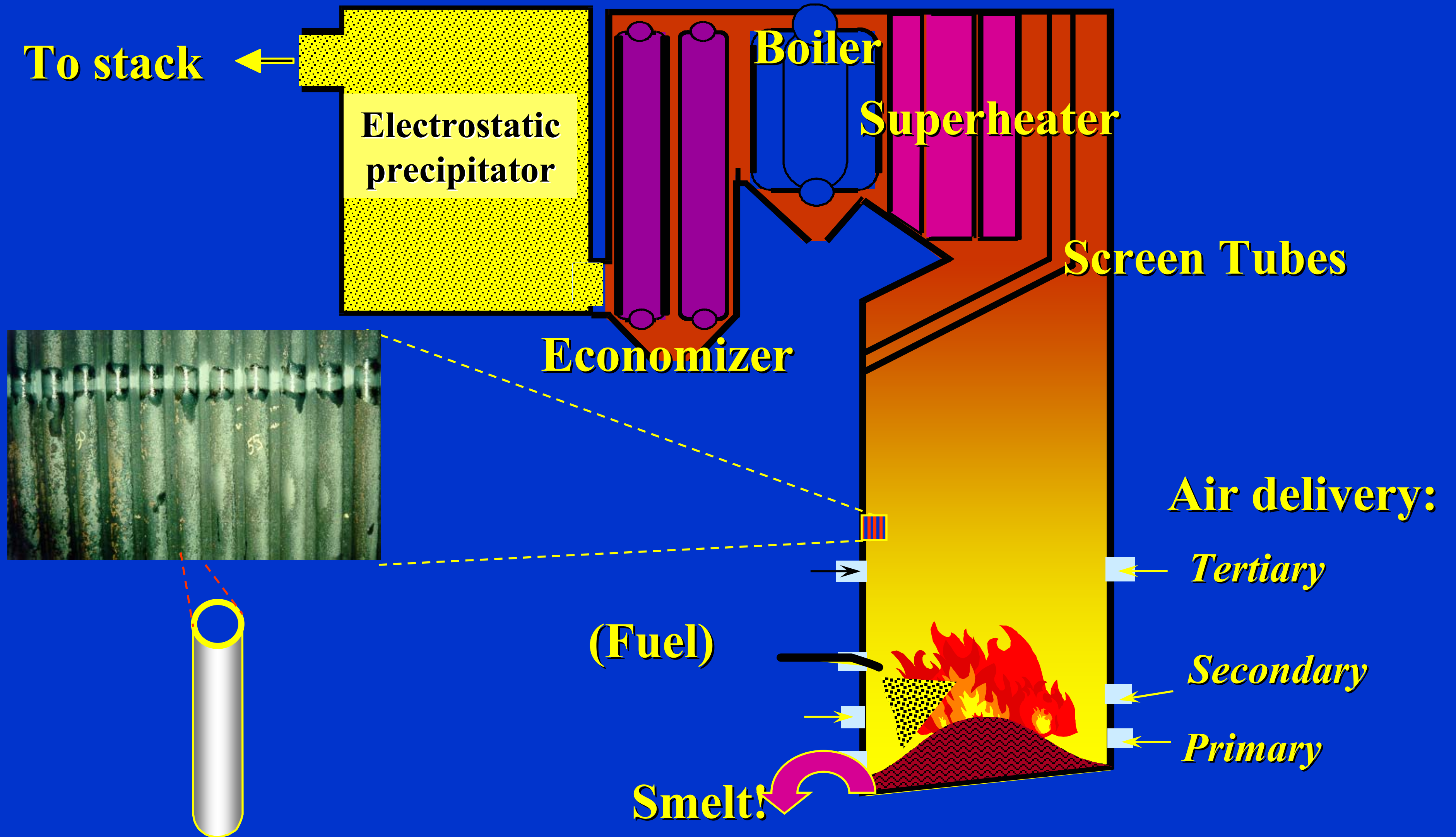
Preet M. Singh and Steve Pawel@*

** Institute of Paper Science & Technology at Georgia Tech, Atlanta, GA*

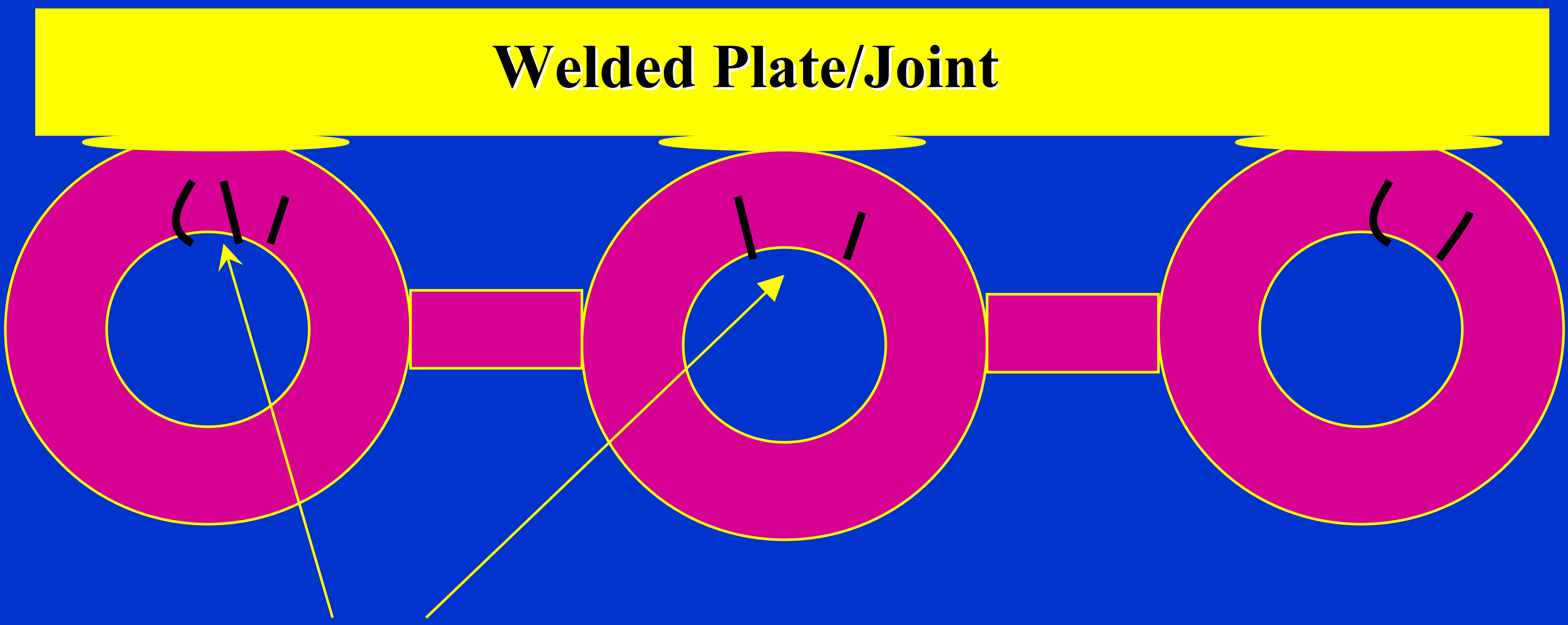
@ Oak Ridge National Laboratory, Oak Ridge, TN

DOE Project #DE-FC07-01ID1443

Industrial Boilers



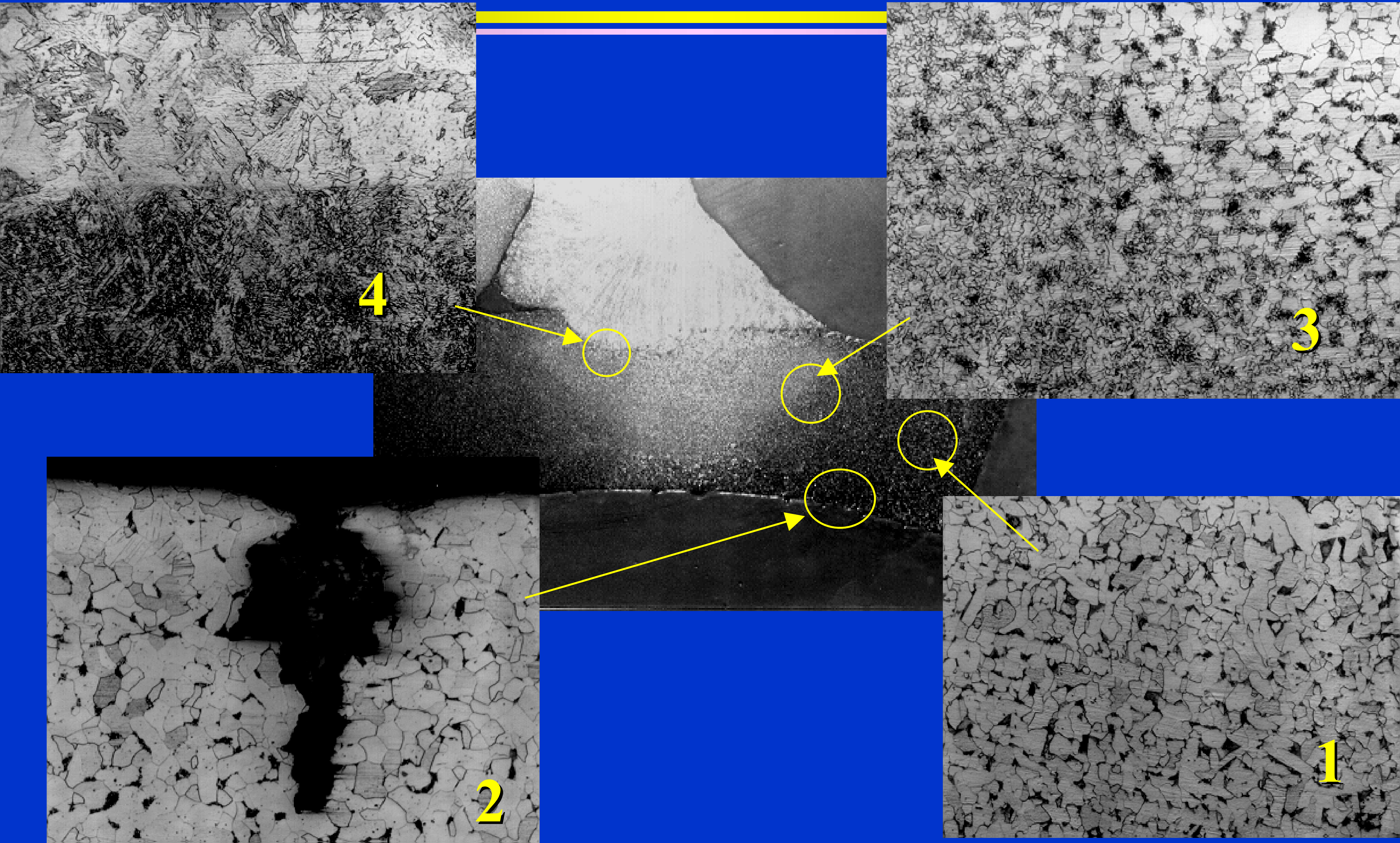
Stress Assisted Corrosion in Waterwall Tubes



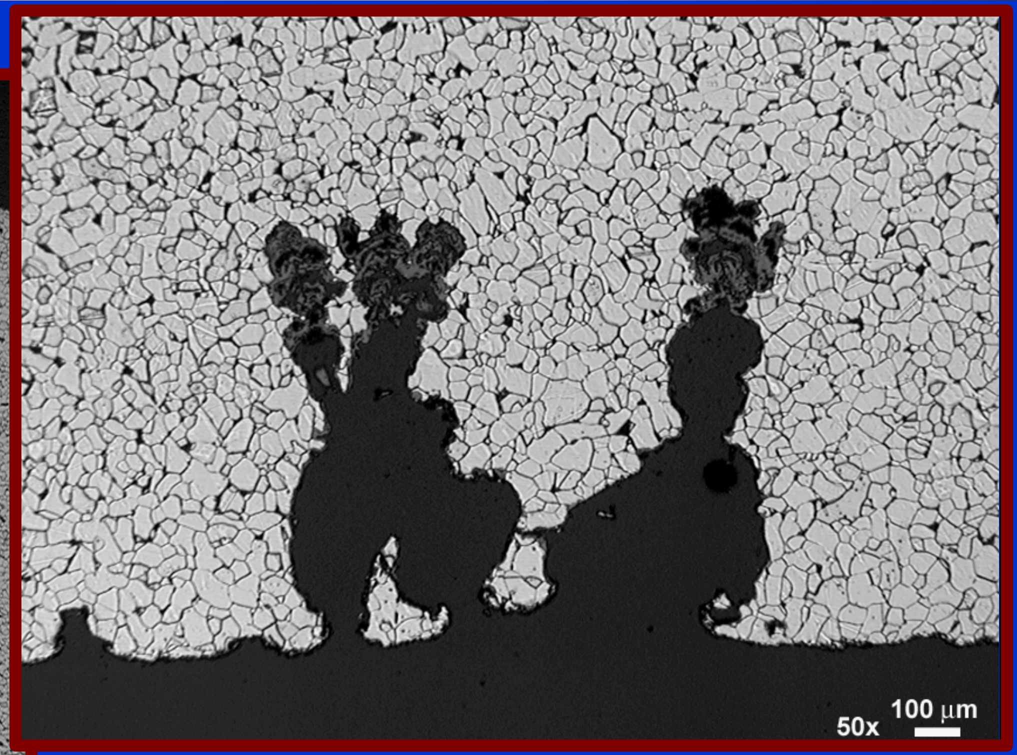
Stress Assisted Corrosion/ Cracking

Waterside Cracks in Waterwall Tube Near Attachment Weld

Microstructure of Carbon Steel Near Weld Attachment

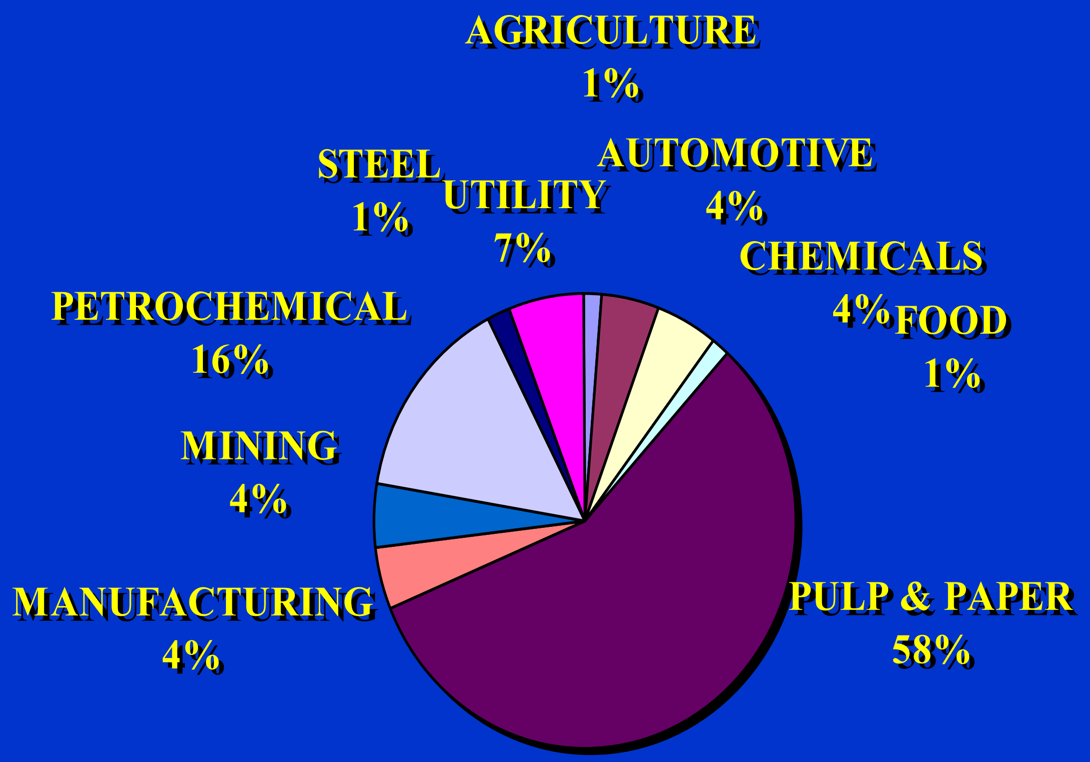


SAC in Recovery Boiler Tubes



Industrial Boilers and SAC

- SAC is Experienced in Various Industrial Boilers



Survey Data from Hercules-BetzDearborn

Project Objective

To Clarify Mechanisms Involved in Stress Assisted Corrosion (SAC) of Boiler Tubes to Determine Key Parameters in its Mitigation and Control

- **Microstructure**
- **Water Chemistry**
- **Stress**
  - **Residual Stresses Due to Welding**
  - **Operational Stresses**

Project Team

- **Oak Ridge National Laboratory -** Dr. Steve Pawel
- **Institute of Paper Science and Technology -** Dr. Preet Singh
- **Others**
  - Lawrence Livermore National Laboratory - Dr. Mike Quarry
- **Industrial Partners**

Dr. W.B.A. Sharp– MeadWestvaco
Mr. Steve Lukezich – MeadWestvaco
Mr. Paul B. Desch - ONDEO- Nalco
Dr. Peter Gorog - Weyerhaeuser Company

Mr. John Hainsworth – B&W
Dr. Ray Vasudevan - International Paper
Mr. Mike Cooper – Longview Inspections

- **Other Project Advisors**

Dr. Barry Dooley – EPRI
Dr. Jim Keiser - ORNL

Mr. Mel Esmacher - GE Specialty Materials
Mr. Karl Morency – Georgia Pacific

Main Project Tasks

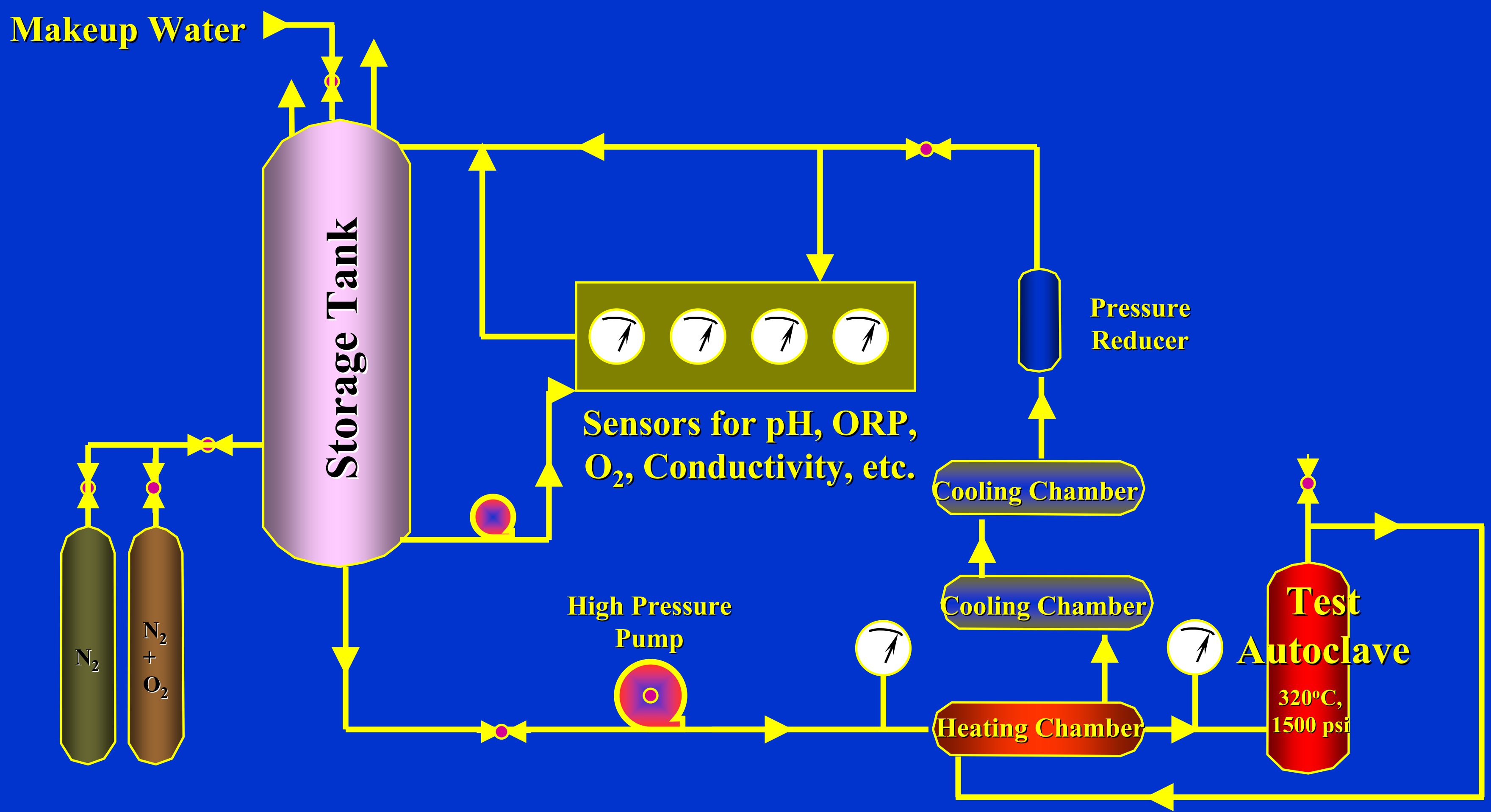
- **Task 1:** ***Laboratory Simulation of SAC – FY 2003***
  - ***[IPST]***
- **Task 2:** ***Material Characterization – FY 2003***
  - ***[ORNL and IPST]***
- **Task 3:** ***Evaluation of Stress Effects***
  - ***[ORNL]***
- **Task 4:** ***Evaluation of Environmental Effects***
  - ***[IPST and ORNL]***
- **Task 5:** ***Communication to US Industry***
  - ***[IPST and ORNL]***

Project Progress in FY2003

Task 1 – Laboratory Simulation of SAC

- **Develop Recirculation-Loop Autoclave Setup to Simulate Boiler Tube Environment**
- **Water Chemistry Variables**
  - **Dissolved Oxygen**
  - **pH**
  - **Cl^-, SO_4^{-2}, and Other Ions**
    - **Conductivity**

Autoclave with Recirculation Loop



Capabilities of Recirculation Autoclave

- Temperature up to 340^{o}C and Pressure up to 2000 psi
- Continuous Monitoring
  - pH, Dissolved Oxygen, Conductivity, and Redox Potential
- Electrochemical Measurements and Long Term Corrosion Tests
  - *Stressed and Non- Stressed Samples*
- Tests to Monitor the Formation and Stability of Magnetite Film on the Tube Material
- Crack Growth Under Different Stress Conditions
    - Wedge Loaded Pre-Cracked Specimens
    - Slow Strain Rate Tests

Task 2: Material Characterization

- Examine Tube Specimens Removed from Boilers
  - With and Without SAC
- Data-Mining with Project Partners Using Previous Inspection/Failure Analysis Reports

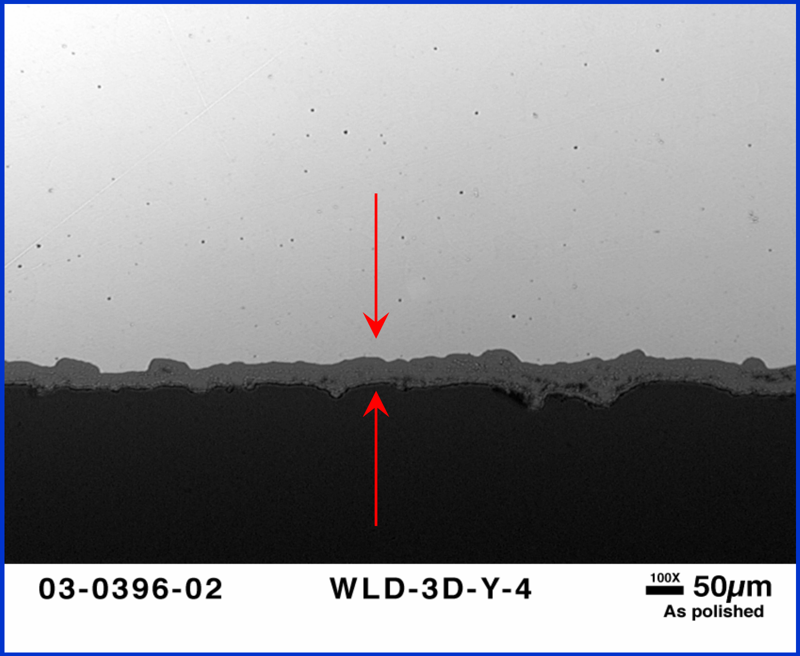
Task 2: *Material Characterization*

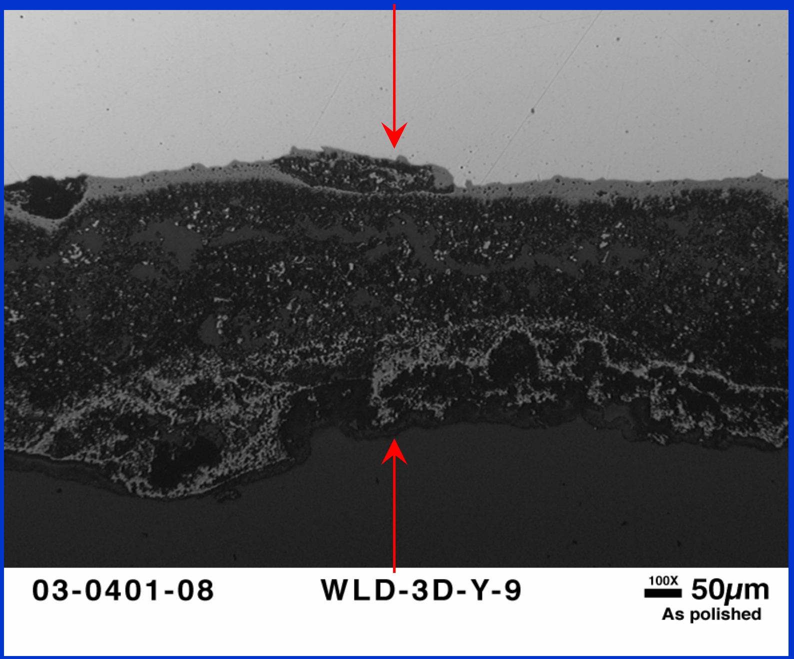
- Almost 900 Linear Feet Failed Tubes were Received From Weyerhaeuser and MeadWestvaco Mills
- Largest Panel was 20 Feet Long by Four Tubes Wide
- Tubes were Sectioned and Prepared for Failure Analysis
- Inner Surface had Oxide Scale
- Scale Thickness Varied from Less than 50 Microns to More than 500 Microns at Different Areas
- Cracks were Generally Packed with this Oxide Film
- Metallography Revealed Stress Assisted Corrosion in Numerous Welded Sections

Waterside Cracks in Waterwall Tube Near Attachment Weld

<u>**Stress Assisted Corrosion Under Welded Joints on Inner Surface of Waterwall Tubes**</u>

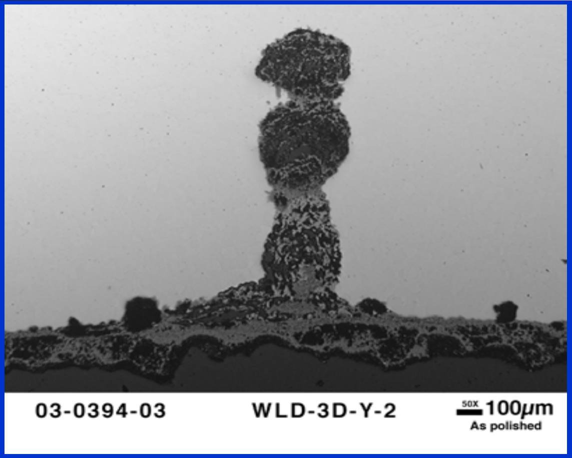
Oxide Scale on Failed Tubes

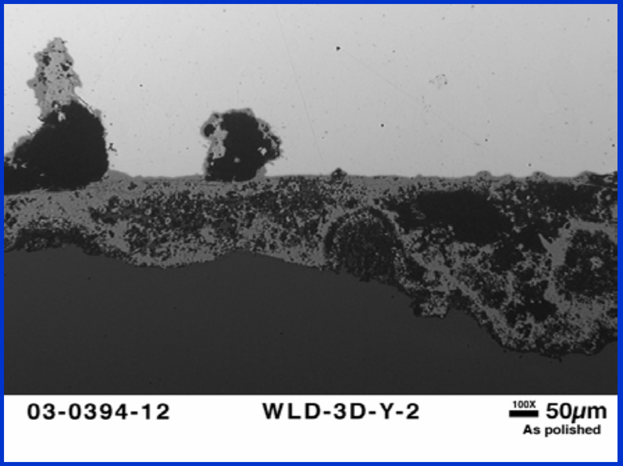


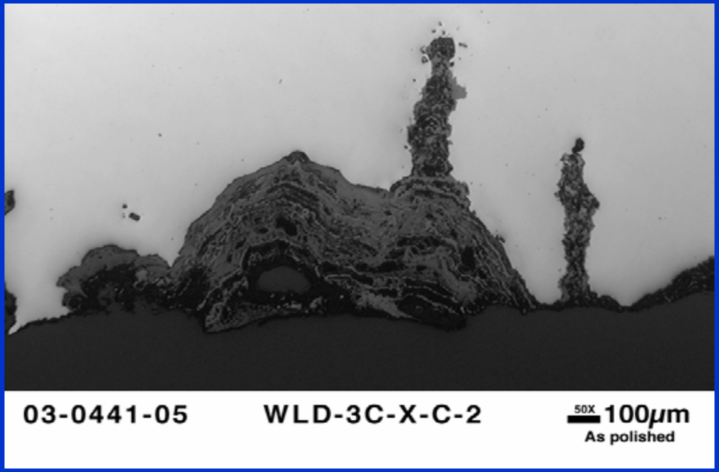


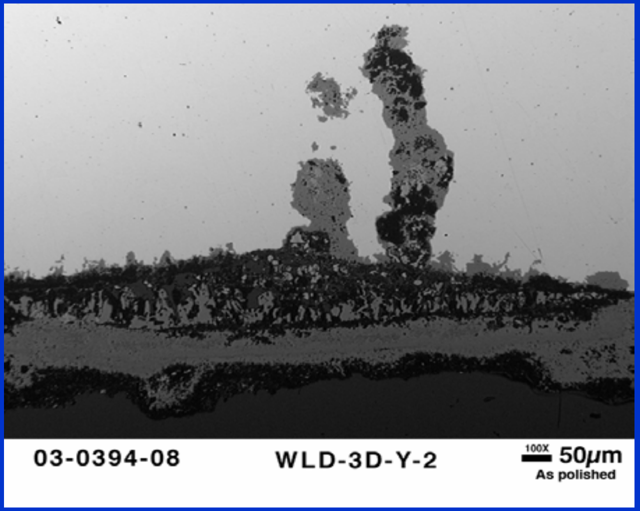
Oxide Scale on Water-Touched Tube Surface

Stress Assisted Corrosion Under Welded Sections



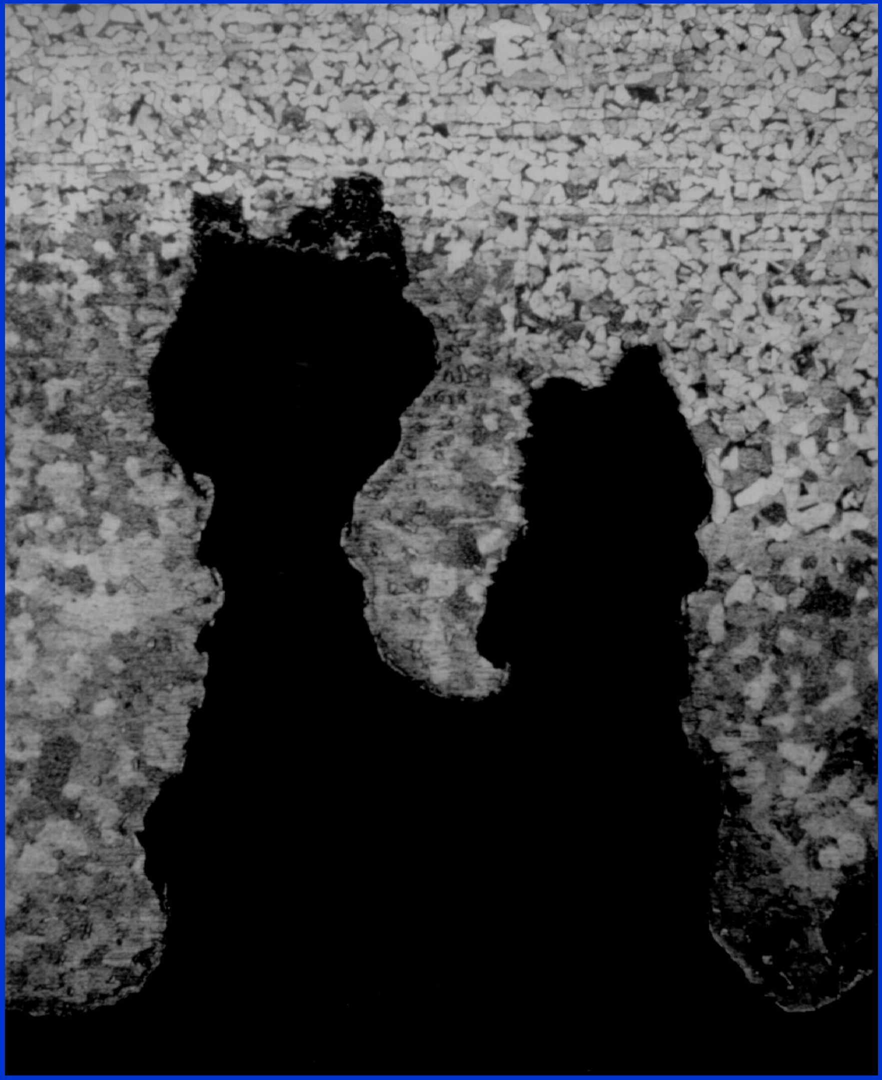




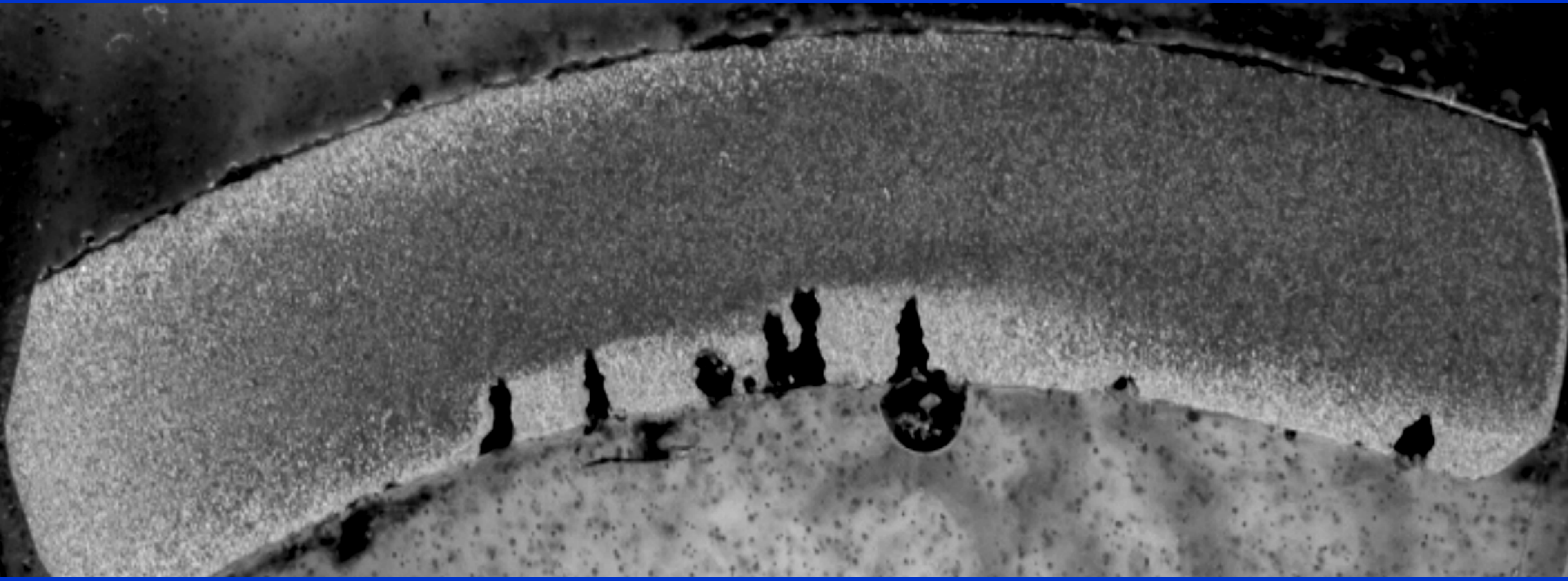


Role of C-Steel Microstructure on initiation of Stress Assisted Cracks

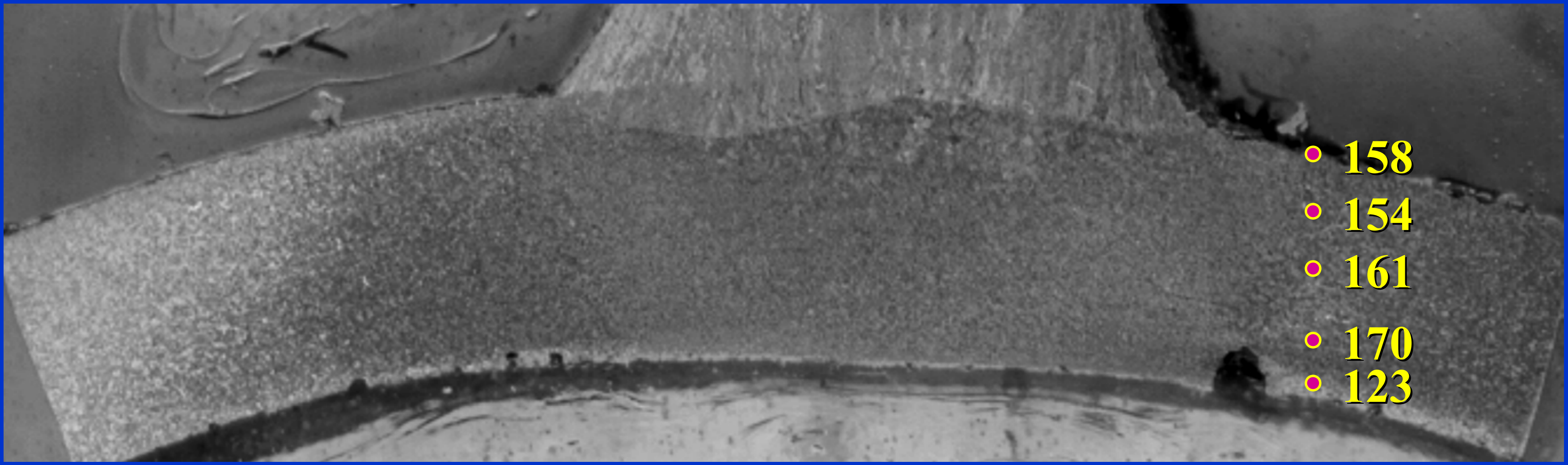
Role of C-Steel Microstructure on initiation of Stress Assisted Cracks



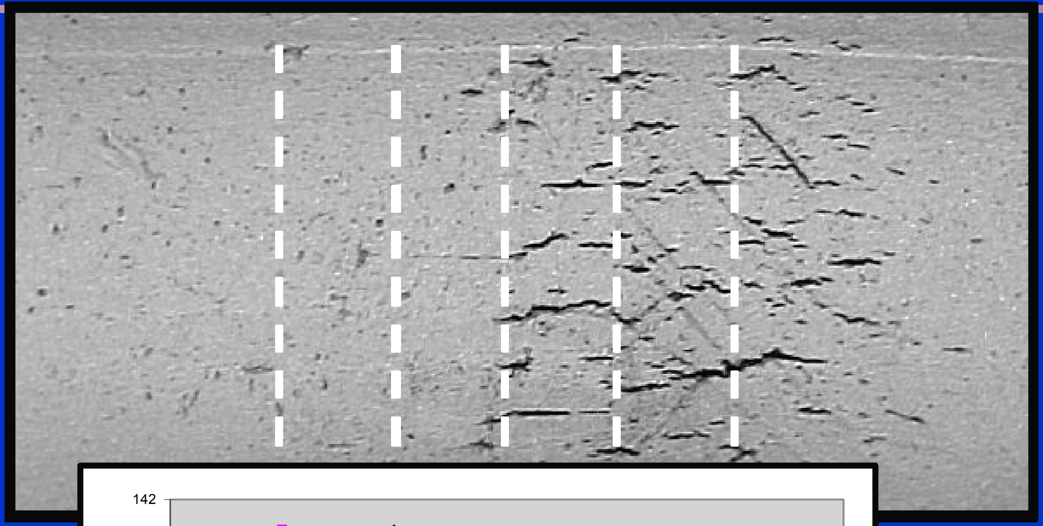
Role of C-Steel Microstructure on Initiation of Stress Assisted Cracks

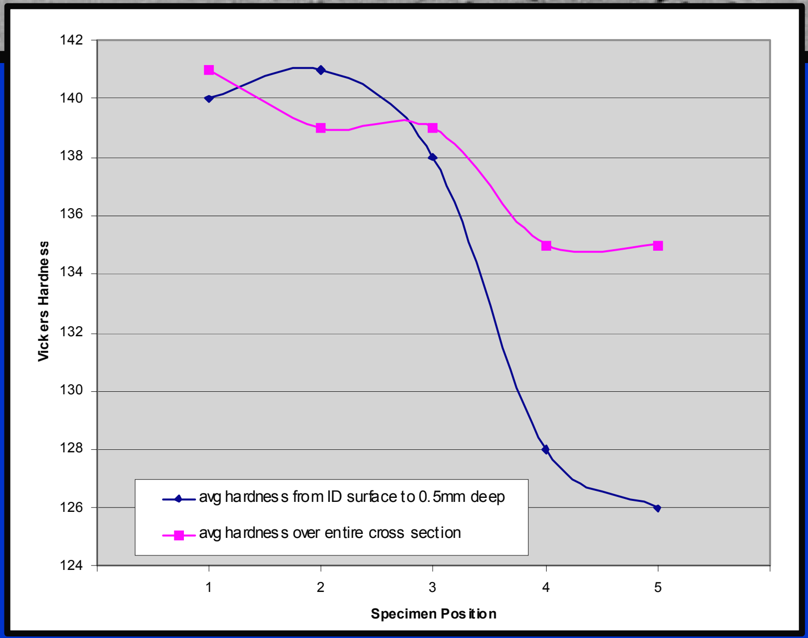


Microhardness *(VHN)* of C-Steel Waterwall Tubes in Area with SAC



Microhardness *(VHN)* of C-Steel Waterwall Tubes in Area with SAC





Evaluation of Non-Destructive Techniques to Detect SAC

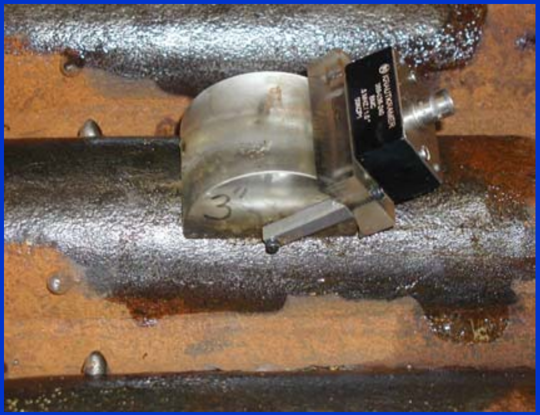
- Comprehensive Analysis of Boiler Tube Panels Includes NDE and Destructive Techniques
  - Guided (Longitudinal) Waves Introduced from Cold Side of Tube Panel
  - Circumferential Waves Introduced from Process Side of Tube Panel
  - Radiography with Standard and Specialized Film Placement.
  - Bright Light Borescope Evaluation of All 900 Feet of Tubing

Evaluation of Non-Destructive Techniques to Detect SAC

Circumferential Wave Instrument

Large Array Transducer Used for Longitudinal Wave Technique

Longitudinal Wave Technique



Small Transducer Used for Longitudinal Wave Technique

Results from NDE Evaluations

- NDE Techniques Selected were not Effective for Locating Oxide Accumulations or the Longitudinal Stress Assisted Cracking
- Circumferential Wave Technique has Geometry Limitations Near Most Attachment Welds
- Longitudinal Wave Technique Detects Only Circumferential Flaws and is Presently Insufficiently Sensitive
- Radiography was not Sufficiently Sensitive, Especially Near Attachments.
- Right-Angle Borescope Viewing could not Distinguish Oxide Accumulation

Evaluation of Non-Destructive Techniques to Detect SAC

- Panels were Cut Longitudinally to Facilitate Visual Inspection
- Metallography of Specimens from Areas With and Without Attachment Welds Revealed SAC Cracks
- None of the Cracks Detected from Metallography were Detected by Selected NDE Techniques

Project Status Summary

Task ID	Milestone	Planned Completion	Actual Completion	Comments
1.0	**Lab simulation of SAC**			
1.1	Establish autoclave operation	April 2003	Completed	Autoclave and heaters are working satisfactorily
1.2	Develop tensile test rig	August 2003		
1.3	Simulate SAC in lab tests	Sept. 2004		
1.4	Oxide growth experiments	Sept 2004		
2.0	**Material characterization**			
2.1	Examine tubes with SAC	Sept. 2003	In-progress	Various tubes were received and were examined at ORNL and IPST
2.2	Document inspection reports	Dec. 2003	In-progress	
2.3	Inspections to assess SAC rate	Sept. 2004		
3.0	**Evaluation of stress effects**			
3.1	Document failure reports	April 2003	In-progress	Some data was received and is being reviewed. Required information is missing in most cases
3.2	Deploy field strain gages	Dec. 2003		
3.3	Model internal stress/strains			
4.0	**Environmental effects**			
4.1	Assess key chemistry data	Mar. 2004		
4.2	Deploy on-line monitoring	April 2004		
4.3	Document effect of cleaning	Sept. 2003		
5.0	**Communication to US industry**			Presentations were made at TAPPI and NACE meetings and appropriate Committees attended by US industry reps.
5.1	Technical review meetings	Every six months	In-progress	Second meeting will be held in June 2003
5.2	Special topic workshops	Once a year		
5.3	Final report	Feb. 2005		

Future Tasks

- **Task 3:** ***Evaluation of Stress Effects***
  - ***Finite Element Modeling of Stresses due to Welding and Operation on Carbon Steel and Composite Tubes - ORNL***
- **Task 4:** ***Evaluation of Environmental Effects***
  - ***Tests in Recirculation Autoclave to Evaluate Relative Effects of Important Operating Parameters***
- **Task 5:** ***Communication to US Industry***
  - ***Through Seminars, Target Workshops, and Publications***

Roadmap for Commercialization

- Key Findings Will be Shared and Implemented Via Technical Symposia Targeted to
  - Boiler Manufacturers
  - Water Treatment Companies
  - Boiler Owners
  - Consultants
- Publications and Presentations

Energy Benefits

- *Increase Energy Efficiency Simply by Decreasing the Frequency and Duration of Maintenance Outages.*
- *Will Prevent Catastrophic/Emergency Shut-downs of Operating Boilers*
- *By Increasing Boiler Operation Time and Efficiency by Just 0.5%*
- *Energy Savings Calculations were Based on the Roadmap for Process Heating Technology*
  - *sponsored by the Industrial Equipment Association and the U.S. Department of Energy, Office of Industrial Technologies, March 16, 2001*

Energy Savings

Impact by the year 2020					
ENERGY SAVINGS	Electricity	Gas	Oil	Coal	Total Energy Savings
Vision Industry	[billion kWh]	[billion ft3]	[million barrels]	[million tons]	[trillion BTU's]
Petrochemical	0.13	4.0	0.05	0.04	6.25
Chemical	0.08	2.3	0.025	0.01	5.5
Other Manf.	0.07	2.2	0.025	0.01	5.0
Metal	0.05	1.8	0.02	0.01	2.5
Glass	0.07	2.0	0.02	0.01	3.0
Paper	0.02	0.05	0.002	.003	0.75
Total Savings	0.42	12.4	0.14	0.083	23

Energy Impact *(in Dollars)*

Impact by the Year 2020	
Energy Cost Savings ***Vision Industry***	**Energy Savings [Million $/Year]**
Petrochemical	48
Chemical	28
Other Manufacturing	25
Metal	12
Glass	15
Paper	5
Total	**133**

Environmental Impact

Impact by the Year 2020		
Environmental Savings	[Thousand tons/year]	
	CO_2	NO_x
Petrochemical	100	0.9
Chemical	60	0.5
Other Manf.	50	0.45
Metal	40	0.35
Glass	48	0.4
Paper	12	0.1
Total	310	2.7

INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY
1929

ornl
UT-BATTELLE